

WHAT IS CLAIMED IS:

1. A fuel injection control device for a direct fuel injection engine, comprising:
a fuel injection valve configured and arranged to directly inject a first fuel stream
per cycle into a combustion chamber;

5 at least one sensor configured and arranged to determine at least one engine
operation parameter that affects formation of a stratified air-fuel mixture inside the
combustion chamber; and

a controller configured to selectively control the fuel injection valve to use a first
fuel injection timing when the controller determines that a stratified air-fuel mixture will
10 be difficult to form during a second fuel injection timing based on a determination of the
engine operation parameter by the at least one sensor, the first fuel injection timing being
set to control the injection valve to inject the first fuel stream during an intake stroke while
a piston in the combustion chamber is approximately at an intake top dead center position
such that a majority of the first fuel stream injected from the fuel injection valve is
15 received inside a cavity formed on the piston.

2. The fuel injection control device as recited in claim 1, wherein
the fuel injection valve is positioned at a substantially upper center portion of the
combustion chamber such that the first fuel stream is injected at the cavity formed in a
20 substantially center portion of a top surface of the piston.

3. The fuel injection control device as recited in claim 2, wherein
the fuel injection valve is configured and arranged to inject the first fuel stream
with a substantially hollow cone shape.

25 4. The fuel injection control device as recited in claim 1, wherein
the controller is further configured to determine that the stratified air-fuel mixture
will be difficult to form inside the combustion chamber based on determining engine
temperature of the direct fuel injection engine being lower than a prescribed temperature.

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5. The fuel injection control device as recited in claim 1, wherein the controller is further configured to determine that the stratified air-fuel mixture will be difficult to form inside the combustion chamber based on determining fuel pressure being lower than a prescribed fuel pressure.

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6. The fuel injection control device as recited in claim 1, wherein the controller is further configured to inject the first fuel stream in an amount that corresponds to a total fuel injection amount for a single combustion cycle when using the first fuel injection timing.

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7. The fuel injection control device as recited in claim 6, further comprising the controller is further configured to prohibit the fuel injection valve from using the first fuel injection timing based on the controller determining a fuel diffusion parameter indicative of excessive diffusion of the fuel injected in the first fuel stream such that the stratified air-fuel mixture will not be formed at a time of ignition inside the combustion chamber when using the first fuel injection timing.

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8. The fuel injection control device as recited in claim 7, wherein the controller is configured to determine that the fuel injected in the first fuel stream will be excessively diffused based on engine temperature of the direct fuel injection engine as the fuel diffusion parameter.

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9. The fuel injection control device as recited in claim 7, wherein the controller is configured to determine that the fuel injected in the first fuel stream will be excessively diffused based on fuel pressure as the fuel diffusion parameter.

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10. The fuel injection control device as recited in claim 7, wherein the controller is configured to determine that the fuel injected in the first fuel stream will be excessively diffused based on a number of combustion cycles performed since the direct fuel injection engine was started as the fuel diffusion parameter.

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11. The fuel injection control device as recited in claim 7, wherein
the controller is configured to determine that the fuel injected in the first fuel
stream will be excessively diffused based on rotational speed of the direct fuel injection
engine as the fuel diffusion parameter.

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12. The fuel injection control device as recited in claim 7, wherein
the controller is further configured to selectively control the fuel injection valve
using the second fuel injection timing such that the first fuel stream is injected during a
compression stroke with a majority of the first fuel stream being received inside the cavity
when the controller determines the fuel injected in the first fuel stream will be excessively
diffused such that the stratified air-fuel mixture will not be formed at the time of ignition
when using the first fuel injection timing.

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13. The fuel injection control device as recited in claim 7, wherein
the controller is further configured to calculate a first fuel vaporization ratio of fuel
inside the combustion chamber based on the fuel diffusion parameter when using the first
fuel injection timing,

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the controller is further configured to calculate a first fuel injection amount
obtained by compensating an amount of fuel in the first fuel stream when using the first
fuel injection timing upon the first fuel vaporization ratio indicating a part of the fuel in
the first fuel stream will not be combusted because the part of the fuel is vaporized and
drawn outside of the cavity,

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the controller is further configured to compare the first fuel injection amount to the
second fuel injection amount that is injected when using the second fuel injection timing
in which the first fuel stream is injected during the compression stroke with a majority of
the first fuel stream being received inside the cavity, and

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the controller is further configured to use the second fuel injection timing when the
second fuel injection amount is larger than the first fuel injection amount.

14. The fuel injection control device as recited in claim 13, wherein
the controller is further configured to calculate the first fuel vaporization ratio
based on at least one of the engine temperature of the direct fuel injection engine, the

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rotational speed of the direct fuel injection engine, the number of combustion cycles performed since the direct fuel injection engine was started and the fuel pressure as the fuel diffusion parameter.

5 15. The fuel injection control device as recited in claim 13, wherein
the controller is further configured to calculate a second fuel vaporization ratio of
the first fuel stream when using the second fuel injection timing to inject the first fuel
stream during the compression stroke such that a majority of the first fuel stream is
received inside the cavity based on the at least one fuel diffusion parameter, and
10 the controller is further configured to compensate the second fuel injection amount
of the first fuel stream injected during the compression stroke using the second fuel
injection timing such that the majority of the fuel stream is received inside the cavity
based on the second fuel vaporization ratio when the controller determines to inject the
first fuel stream by using the second fuel injection timing.

15 16. The fuel injection control device as recited in claim 3, wherein
the controller is further configured to inject a second fuel stream per cycle when
using the first fuel injection timing such that the second fuel stream is injected during the
compression stroke after the first fuel stream is injected during the intake stroke while the
20 piston is approximately at the intake top dead center position.

 17. The fuel injection control device as recited in claim 16, wherein
the controller is further configured to inject the first fuel stream when using the
first fuel injection timing such that the first fuel stream is directed toward a substantially
25 center portion of a bottom wall surface of the cavity having a substantially cylindrical
peripheral wall surface smoothly connected to the bottom wall surface, and
the controller is further configured to inject the second fuel stream when using the
first fuel injection timing such that the second fuel stream is directed toward a radially
outer periphery of the bottom wall surface of the cavity.

18. The fuel injection control device as recited in claim 16, wherein the controller is further configured to inject the first fuel stream when using the first fuel injection timing such that the first fuel stream is directed toward a lower bottom wall surface of the cavity including

- 5 a substantially cylindrical lower peripheral wall surface smoothly connected to the lower bottom wall surface,
- a substantially cylindrical upper peripheral wall surface that is positioned higher than the lower peripheral wall surface and has a larger diameter than the lower peripheral wall
- 10 surface, and
- a ring-shaped upper bottom wall surface disposed between the lower peripheral wall surface and the upper peripheral wall surface and smoothly connected to the upper peripheral wall surface, and

15 the controller is further configured to inject the second fuel stream when using the first fuel injection timing such that the second fuel stream is directed toward the upper bottom wall surface of the cavity.

19. The fuel injection control device as recited in claim 16, wherein
20 the controller is further configured to inject the first fuel stream and the second fuel stream when using the first fuel injection timing upon determining engine temperature of the direct fuel injection engine is lower than a prescribed temperature.

20. The fuel injection control device as recited in claim 19, wherein
25 the controller is further configured to steadily retard a first divided fuel injection timing of the first fuel stream as the temperature of the direct fuel injection engine gets higher.

21. The fuel injection control device as recited in claim 19, wherein
the controller is further configured to steadily decrease a fuel injection amount of
the first fuel stream as the temperature of the direct fuel injection engine gets higher when
using the second fuel injection timing.

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22. The fuel injection control device as recited in claim 19, wherein
the controller is configured to detect the engine temperature of the direct fuel
injection engine by speculating at least one of a top surface temperature of the piston and
an inside temperature of the combustion chamber.

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23. The fuel injection control device as recited in claim 19, wherein
the controller is further configured to steadily retard a first divided fuel injection
timing of the first fuel stream within a range that the substantially hollow cone shape first
fuel stream remains directed at the lower bottom wall surface.

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24. The fuel injection control device as recited in claim 16, wherein
the controller is further configured to inject the first fuel stream and the second fuel
stream when using the first fuel injection timing upon determining fuel pressure is lower
than a prescribed fuel pressure.

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25. The fuel injection control device as recited in claim 24, wherein
the controller is further configured to steadily decrease a fuel injection amount of
the first fuel stream as the fuel pressure gets higher when using the first fuel injection
timing.

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26. The fuel injection control device as recited in claim 16, wherein
the controller is further configured to inject the second fuel stream during the
compression stroke when the piston is at a position lower than a position of the piston
when the first fuel stream is injected during the intake stroke when using the first fuel
injection timing.

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27. A fuel injection control method for a direct fuel injection engine, comprising:

determining at least one engine operation parameter that affects formation of a stratified air-fuel mixture inside a combustion chamber;

5 determining whether to use one of a first fuel injection timing and a second fuel injection timing when using the second fuel injection timing will be difficult to form the stratified air-fuel mixture based on a determination of the engine operation parameter; and

10 injecting a first fuel stream using the first fuel injection timing to inject the first fuel stream while a piston is approximately at an intake top dead center position such that a majority of the first fuel stream is received inside a cavity formed on the piston, when a determination has been made that using the second fuel injection timing will be difficult to form the stratified air-fuel mixture.

28. A fuel injection control device for a direct fuel injection engine, comprising:

15 fuel injection means for directly injecting a first fuel stream per cycle into a combustion chamber;

engine operation parameter detecting means for determining at least one engine operation parameter that affects formation of a stratified air-fuel mixture inside the combustion chamber; and

20 control means for controlling the fuel injection means to select one of a first fuel injection timing and a second fuel injection timing when the control means determines that using the second fuel injection timing will be difficult to form the stratified air-fuel mixture based on a determination of the engine operation parameter detecting means, the control means being configured to control the fuel injection means during the first fuel
25 injection timing to inject the first fuel stream while a piston in the combustion chamber is approximately at an intake top dead center position such that a majority of the first fuel stream injected from the fuel injection means is received inside a cavity formed on the piston.